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This paper presents the Advanced Tethered Vehicle (ATV) design considerations, system description, and test results.

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Advanced Tethered Vehicle, Design and Description

ABSTRACT

The Advanced Tethered Vehicle (ATV) is a remotely operated submersible work system designed to carry out Navy missions at ocean depths down to 20,000 feet. It consists of a submersible vehicle, tether cable, handling system, control station, and auxiliary equipment. The vehicle is neutrally buoyant and carries two force feedback manipulators and interchangeable tools. Integrated system testing was completed in June 1990 with a successful dive to 20,600 ft in the Molokai Fracture Zone near the Hawaiian Islands.

This paper presents the Advanced Tethered Vehicle (ATV) design considerations, system description, and test results.

BACKGROUND

Unmanned Vehicle Systems (UVSs) built for ocean applications require the application of a wide variety of technologies. The environment is electrically conductive, acoustically transmissive, electromagnetically opaque, and has high optical attenuation. It is corrosive and squeezes the system by an additional atmosphere for every 33 ft of descent. It contains sea life which is capable of chewing holes in vulnerable components and making strange noises which interfer with acoustic sensors. In addition to the sub-surface nastiness, the surface in generally in constant vertical motion and the winds combine with this motion to make life on a surface platform miserable for anyone with a tendency for motion sickness. Remotely operated systems which operate in this environment are necessarily complex. The successful design of these systems requires a detailed knowledge of the subtle interactions between the various components of the system as well as between the system and the environment.

The Naval Ocean Systems Center (NOSC) has been developing remotely operated vehicle (ROV) systems since 1965, continually improving capability as technology has evolved. NOSC experience includes the development of the Cable-controlled Underwater Recovery Vehicle (CURV), the Remote Unmanned Work System (RUWS), the Mine Neutralization Vehicle, and the Work System Package (WSP). When combined with in-house technology development in fiber optics and digital telemetry, this background permits NOSC to successfully develop unmanned vehicle systems for a variety of applications.

SYSTEM CONCEPT DEVELOPMENT

Since there is no perfect configuration, system concept selection is primarily a matter of choosing the problems one must deal with. With simplicity high of the list of desirable acharacteristics, a positively buoyant vehicle with a continuous cable between the ship and vehicle was chosen. To support the two simultaneous television cameras desired for work and to reduce the size of the umbilical cable, optical fibers were selected as the communication medium. The principal problems to be solved were identified from prior system development to be launch/recovery of the vehicle and the development of the electro-optic-mechanical umbilical cable and associated optical telemetry system. The remainder of the system could be designed based on prior experience, avoiding problems encountered previously and incorporating features to simplify operation and maintenance and improve reliability. Non-developmental equipment was used to the maximum extent practical.

The ATV concept is shown in Figure 1. Described in more detail below, the system consists of a neutrally buoyant vehicle, an umbilical cable, a control van and a surface handling system. These subsystems are connected by an electrical subsystem which includes sensors, circuits, telemetry and power components.

Two unique features set this system apart from other approaches. The first is that the vehicle is launched and recovered using a steel lift line separate from the umbilical cable and is towed by the ship while floats are attached to the cable near the vehicle. This approach greatly reduces stress on the vehicle cable termination, allowing a less strength-efficient but faster cable retermination procedure. It also permits the vehicle to be handled with power off and allows a totally reversible launch/recovery procedure. The second feature is a ram tensioner for the lift line. This eliminates lift line snap loads during launch/recovery of the vehicle and also permits the umbilical
cable to be supported by the lift line during deep operation to reduce dynamic loading (reference 2).

SYSTEM DESCRIPTION

Vehicle

The vehicle frame is constructed from standard aluminum alloy 5086 shapes and includes side and front fairings to reduce drag and to protect the interior components. Syntactic foam modules are mounted on the top and titanium pressure housings containing electrical and optical components are located on the bottom level. Hydraulic manifolds and plumbing are located in a center section. A television camera and sonar used in transit to the target, are mounted behind the front fairing. The umbilical cable is attached to a boom at the front of the vehicle. The boom is pivoted to allow the cable to exit the vehicle horizontally during surface handling (Figure 2) and vertically during submerged operation. The work package is mounted on the aft end. The vehicle is lifted by a bail on top. The vehicle is 198 in long by 115 in wide and 84 in high. Its air weight is 13,000 lb. In-water buoyancy is between 50 and 150 lbs.

The work package consists of two manipulators, four television cameras, a 35 mm film camera and strobe, and a variety of tools and lights. The manipulators are identical master/slave units with force feedback. Of the four TV cameras, two are used as a stereo pair, one has a zoom lens, and one acts as a viewfinder for the film camera. The stereo pair and zoom cameras are mounted on pan and tilt units. Hydraulically operated tools are mounted on a support tray below the manipulators and include a rotary drive to which an abrasive cutoff wheel, drill, or impact wrench can be attached and independent linear tools consisting of a spreader, cable cutter, jack and grabber. The linear tools are standard surface units which have been modified slightly for underwater use.

The vehicle propulsion system incorporates five hydraulically powered thrusters: Two vertical, two axial, and one transverse. The hydraulic system consists of dual, variable displacement pumps which operate at 3000 psi with a total flow of 26 gpm. Servo valves are used to control the thrusters, pan and tilt units, and the tool package motor. The tool hydraulic system is isolated from the main vehicle hydraulics by a hydraulic motor/pump assembly. A servo valve controls the rotary tools and a solenoid controlled pressure intensifier drives the linear tools. Sensors used to monitor the hydraulic systems include pressure transducers, thermocouples, flow meters and a potentiometer for compensator level. A level switch on the main vehicle hydraulic system compensator shuts down the pumps if the compensator level drops below 25%. The switch can be manually overridden if necessary.

An explosively released, 250 lb weight can be dropped in an emergency or to provide additional lift. A cable cutter and termination release are also provided to separate the vehicle from the umbilical cable. These devices can be actuated through the umbilical or acoustically using the navigation system.

Cable

The 23,000 ft long umbilical cable is the principal developmental item in the system. It incorporates three power conductors, three multi-mode optical fibers, a Kevlar strength member, and an outer yellow jacket with a black stripe. The black stripe is used to monitor cable twists. The cable cross-section is given in Figure 3 and its characteristics in Table I.

Table I - Cable Characteristics

DC Resistance	9.35	ohms/kft
Insulation Resistance	1,500	megohms/23 kft
Optical Attenuation @ 1.3 um		
No Load	0.6	dB/km
10,000 psi ambient pressure	0.8	dB/km
10,000 lb tension	0.7	dB/km
Safety Factor based on in-water wt.	7.5/8.4*	
Cable Torque	+2/-147*	in-lb
Cable Rotation	0/-1.3*	deg/ft

* measured on samples from both ends

Power

Figure 4 is the overall block diagram of the ATV electrical power distribution. The system includes two diesel generators that provide power for the entire system. Each generator provides 480 volts, 60 Hz, 3-phase power at a capacity of 180 kw. During normal operations, one generator powers the control van and the vehicle and the other powers the surface handling system. If one generator fails, the other generator is able to power the entire system.

In the control van, a 30 KVA transformer steps down the 480 volts to 208 and 120 volts. These voltages power the electronic circuits and equipment in the van and also the utilities such as the air conditioners and lights. The control van contains the high voltage console which has a 100 KVA transformer that steps up the 480 volts, 3-phase input to 2400 volts. This 2400 volt, 3-phase power is then transmitted to the tether cable via slip rings. The high voltage console includes over current trip and ground fault interruption circuits to protect personnel and equipment.

At the vehicle, the 2400 volt, 3-phase power goes to motor switching circuits that control two 25 HP electrohydraulic units. The motor switching circuits were designed and assembled by the David Taylor Research Center. These switching circuits use rugged, heavy duty, reliable vacuum contactors instead of smaller high voltage relays. The decision to tradeoff size for increased reliability has been confirmed; there have been no failures in the motor switching circuits in over 500 hours of operation. Each motor circuit is separately fused and overload current protected. The two electrohydraulic units and their individual motor control circuits provide redundancy in the hydraulic system.

The vehicle also has a five kilowatt transformer that steps down the 2400 volts to lower voltages that power the electronic circuits, equipment, and lights. Each low voltage winding circuit is fused to protect the transformer.

Telemetry

The ATV telemetry subsystem (Figure 5) utilizes wavelength division multiplexing to provide full duplex communications over a single optical fiber. The downlink optical wavelength is 1.55 microns, while the uplink optical wavelength is 1.3 microns. Dichroic filter wavelength division multiplexers separate and integrate the two wavelengths. Commands are transmitted from the surface to the vehicle on the downlink telemetry channel at a 2.5 MBPS data rate. The vehicle instrumentation data, sonar signal, and two realtime video signals are transmitted from the vehicle to the surface on the uplink telemetry channel at a rate of 200 MBPS.

Figure 6 shows the physical configuration of the telemetry subsystem. The surface telemetry circuits are installed in the control van. An optical fiber connects the telemetry circuits to the optical slip ring located in the center of the tether storage reel. Assembled with the optical slip ring are optical switches that couple the optical slip ring to any one of the three fibers in the tether cable. At the vehicle, each of the three fibers is connected to individual electro-optical transmitter and receiver circuits.

Because only one fiber is required for the full duplex communications, there is dual redundancy of fibers and the electro-optical circuits on the vehicle. Any optical fiber can be selected with the system online. This redundancy increases the system reliability and has proven very beneficial during operations.

Sensors

The ATV system incorporates a variety of sensors to enhance operations. A long baseline navigation system is used to determine the vehicle and ship's positions. The vehicle normally operates in the responder mode, but in an emergency situation it can also operate in transponder mode. A pulse scan sonar is used as a forward looking sonar and it can also be tilted vertically to provide altitude information. An altitude sonar with a range of 500 feet determines the vehicle's distance from the ocean floor. A quartz pressure transducer provides vehicle depth information. A fluxgate compass determines the vehicle heading.

Sensors are used to monitor the vehicle's main hydraulic system and the tool hydraulic system. These monitor the hydraulic system's pressure, flow, temperature, and compensation. The main hydraulic system also has a low compensation sensor that automatically shuts off the electrohydraulic power units to prevent seawater intrusion.

Other important sensors in the system are leak detectors in the major electrical housings and tachometers for the thrusters.

Emergency Equipment

The ATV system contain circuits that are activated under emergency situations. These circuits fire electro-explosive devices (EED) that release ballast on the vehicle or release the tether termination. They also activate the tether cutter to severe the tether at the vehicle. These emergency circuits are activated by coded commands via the fiber optic telemetry or by acoustic commands from the surface navigation equipment.

A radio beacon and a light beacon are installed on the vehicle to locate the it on the surface.

Control Station

The control station is located in the control van which is 8'W X 20'L X 8'H. Figure 7 is the layout of the control van. The vehicle operator and the work operator are stationed at the control console. This console contains the controls and displays for operating the vehicle and the work package. A computer graphics display that integrated realtime video with graphics was selected and positioned before the vehicle operator to minimize the operator's required viewing area. The critical functions shown on this integrated display is also displayed elsewhere on the console in case the graphics computer malfunctions.

The tether operator is stationed at the tether control console which contains the controls and displays for operating the tether. The high voltage console has the controls for switching on the high voltage and the displays for monitoring the power. For personnel safety, it is located away from the operators and the exit.

Surface Handling System

The surface handling system consists of an over-center A-frame, ram tensioner, lift line, lift line winch, cable traction drive, cable storage drum, launch/recovery station, and a hydraulic power unit. The ram tensioner is a hydraulic cylinder which acts as a shock absorber to prevent the lift line from going slack as the vehicle is launched/recovered. An additional sheave is provided to allow the tether to be supported from the A-frame by the ram tensioner during deep operations, thus reducing snap loads in the tether due to ship motion. The surface handling system is designed to operate from the ship's stern with a freeboard range of two to five feet. During deployment, the vehicle is placed in the water using the lift line while the ship moves into the seas at 1 kn. While the vehicle is on the surface and being towed by the ship, the tether is reeled out and floats are attached to it near the vehicle. After the floats are attached, the vehicle is maneuvered to the sea floor to accomplish its mission. Vehicle recovery is the reverse of the launch procedure.

TEST RESULTS

Twenty-one dives totalling 248 operating hours were made during Test and Evaluation to the depths indicated in Table II.

Table II - Dive Summary

Requirement			Performed		
Number	Depth (ft)	Bottom Time (hr)	Number	Depth (ft)	Bottom Time (hr)
1	> 500	20	1	8,400	72
2	>18,000	6 ea	2	>18,900	6,10
20	> 500	NR*	21	> 1,000	165
10	>10,000	NR	10	>15,300	31
1	20,000	NR	1	20,600	10

* NR - no specific requirement

System operation during these dives, combined with laboratory and pierside testing, demonstrated that ATV meets all its technical requirements.

Reliability exceeded 90% based on no critical failures in over 248 hours of system operation. Critical failure is defined as one which prevents the system from performing its operational mission, requiring it to be returned to port for repairs, spares, or supplies. All repairs were made aboard ship with a mean time to repair (MTTR) of 1.7 hours.

Navy personnel attended twenty of the twenty-one dives during which all system functions were demonstrated. During this period, they were trained to operate all ATV subsystems. ATV is currently in San Diego for documentation validation and the training of Fleet operators prior to turnover.

REFERENCES

1. Hoffman, R.T., Remotely Operated Vehicle Evaluation: Final Report, NOSC TD 489, July 1982

2. Yumori, I.R., Advanced Tethered Vehicle Surface Handling System Test, NOSC TR 1273, December 1988

FIGURES

TABLES